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BINDERS AND PELLET STABILITY IN DEVELOPMENT OF CRUSTACEAN DIETS[1]

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ABSTRACT

Diets developed for shrimps and prawns require good stability to avoid disintegration from exposure to water and from the manipulation process of the animal during ingestion. Other important considerations in selection of a proper binder include its digestability by the animal and its effect on the textural characteristics of the extruded pellet. Changes in texture may significantly affect acceptability of the food. Alginates have proven to be effective binders, giving adequate pellet stability for up to 48 hours. Binding properties are affected by type and concentration of alginate used, composition of the diet, and presence and levels of sequestrants. Cereal fillers, providing large areas of gelatinized starch, also insure good stability under proper processing conditions. Starch gelatinization is affected by particle size as well as the moisture, time, and temperature of the processing procedure. Pre-gelatinized starches have particular application in imparting desirable stability properties. Ultimate choice may depend upon cost of the binder and its adaptability to large-scale commercial operations.

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INTRODUCTION

Considerable emphasis in crustacean culture is being directed toward development of artificial or synthetic diets to replace live and fresh foods used traditionally in shrimp and prawn culture operations. The particular requirements in form and nutritional characteristics for each stage of shrimp must be considered during development of these diets. Material used in an adult ration must justify its possible additional cost by inducing a commensurate increase in the quality and quantity of the harvested shrimp crop. Rations for feed-out or growth increment purposes entail consideration of cost as well as the nutritional, physical and chemical/biochemical features of the final compounded diet.

As a part of the Sea Grant Program effort at Louisiana State University, in conjunction with the National Marine Fisheries Service Laboratory at Galveston, research is being directed toward development of effective low-cost crustacean diets. Major emphasis is on utilization of nutritionally-valuable byproducts of processing operations of food and fisheries industries. Work on development of adult rations has focused primarily on evaluation of various binding materials which impart sufficient stability to the ration to prevent disintegration during the often lengthy shrimp feeding process. The problem has been discussed at length by Forster and Beard (1969), Meyers et al. (1970), Meyers (1972) and Forster (1972). Further studies are presented in the current paper.

RESULTS AND DISCUSSION

Numerous physical characteristics must be considered in development of diets for juvenile to adult crustaceans. These factors include size and shape, density (sinking rate), texture, and of course, water stability. Pellet stability, or durability, refers to the intactness of the extruded diet when submerged in water, i.e., minimal dissolution and loss of fine particles. Workers recognize that pellet feeding is one of the best means of delivering a composite diet to fish (Hastings, 1969). Similar observations can be applied to crustaceans. In view of the benthic feeding nature of the postlarval animal, the pellet must sink rapidly and be adapted to considerable manipulation by the animal during ingestion. "Worm-like" strings or small pellets (0.15 to 0.3 cm in diameter by 1.25 cm long) appear to be a suitable configuration and size, but this will vary depending on the age of the animal. Sick, et al. (1972) observed that penaeid shrimp are able to feed most readily on pellets 0.3 cm in diameter by approximately 1.5 cm in length.

Texture is also of considerable significance, often directly affecting acceptance or rejection of an otherwise suitable diet. Both texture and stability affect rate of diffusion of dissolved materials (leaching) and concurrently, the attractiveness of the pellet to the juvenile and adult animal. Apparently the pellet

must emit some chemotactically-favorable substance(s). Our observations and those of other workers suggest that shrimp exhibit marked preference for the more odoriferous formulas. Minimization of the search by the animal may be a prime factor in achieving maximal conversion efficiency. Excessive leaching of essential nutrients from poorly-bound rations affects availability of the food to the animal as well as modifying the extant microbiological characteristics of the environment. Maintenance of water quality is of prime importance in shrimp culture, especially in instances of low tolerance by the animal to waste accumulation, high temperatures, increased BOD and conditions of stress. Overfeeding, or intensive feeding, contributes to water fouling, and may result in mass mortalities. Increased stability may be desirable especially during periods of low water temperature in the growing area when animal metabolic activity and concurrent feeding rates are reduced. Duration of pellet stability is thus a function of the physical properties of the pellet, the environmental conditions, as well as the feeding intensity and size of the animals fed.

The many considerations in selection of suitable binder are listed in Table 1. Initial selection will be determined by the immediate proposed application, i.e., nutritional evaluation on a developmental basis or large-scale commercial production wherein realistic economic projections are necessary. Many gums or hydrocolloids may be quite suitable for laboratory and limited aquarial work in which dietary components are to be evaluated, ultimately leading to development of a defined diet. Under these circumstances, cost is not critical compared with that involved in least-cost estimates of multi-tonnage production of a final product. Other considerations include length of water-stability desired, digestibility of the binder by the animal, interaction with other constituents of the diet, and finally, susceptability to attack by microorganisms of the animal's intestinal tract and of the growing area itself. Improved pellet stability will, to a certain extent, reduce rates of microbial deterioration. This will become an important consideration under conditions of intensive cultivation, especially in closed systems where careful control of water quality is critical.

A wide variety of natural, modified and synthetic gums is available as potential binding agents. Studies reported here are concerned with the more common natural gums, various of which are listed in Table 2. These compounds, of land and marine-origin, have wide application in the food industry (Table 3) in view of their ability to emulsify, control water and texture, thus imparting functional properties to food products. We have been largely interested in the water-retention function of gums and rheological properties and their effect on overall stability of the pelleted ration in its use as a crustacean food.

The variety of techniques used in processing fish feeds is summarized in Table 4, and are described at length by Ellis (1969) and Hastings (1969). Our efforts in development of a shrimp ration have involved the extrusion process, with and without prior steam conditioning. The process of hard pelleting usually includes conditioning a ground feed mixture with steam, compressing it by rolling through holes in a die ring, cutting the extruded cylinders into pellets, cooling, and drying. Common catfish chows or pellets are produced in this manner. The Oregon Moist Pellet, processed into a tight dough and extruded via a macaroni machine, has good stability, but requires expensive storage under refrigeration or the removal of 25% moisture to an air-dry condition. In our studies we have fitted a standard commercial or industrial meat grinder with a special delivery tube, with series of 0.25 cm orifices. This process, described subsequently, facilitates extrusion of uniform and separate "strings" of compounded ration. Air-dried pellets show excellent stability and acceptance characteristics over long storage periods.

The expanded pellets, which are prepared utilizing extrusion cooking technology, offer considerable promise in crustacean diet formulation. In this process, high pressure steam, mechanical friction, and flash vaporization of water are combined in an expander to manufacture low bulk density floating pellets. However, density of the pellet can be controlled, so that sinking (high density) pellets can be produced. The processing variables listed in Table 4 are important, especially those affecting degree of starch gelatinization and ultimate stability of the pellet. Physical properties of the feed mixture as well as its composition affect final water stability. Fine grinding of the ingredients is necessary, particularly in the starch-bound rations. The characteristics of the pellet matrix determines textural properties, which may significantly affect continual acceptability of the diet by the animal.

Recently, Hastings, et al. (1971), reported a notable increase in stability of pelleted feeds by increasing the area of gelatinizable starch. In the usual process of steam conditioning, compression, and extrusion of dry particle solids into hard pellets, part of the raw starch present in cereal and vegetable ingredients becomes gelatinized to serve as a binder. Control of the amount of moisture, temperature, and drying time is necessary for the formation of a network of dried starch gel. Binding is often improved by addition to the formula of slowly wetted adhesives or finely ground organic fillers which increase the surface area of gelatinizable material. Other ingredients, i.e., soybean meal, fish meal, distillers solubles, etc. may also be finely ground. Hastings, et al. (1971) determined that it was necessary to find alternate ways to achieve the beneficial effects of moisture time and temperature normally provided in hard-pelleting to achieve greater starch gelatinization. This was done by oven-drying following extrusion. The resulting low moisture, 5 to 6%, and increased starch gelatinization achieved the desired water stability. The amount of starch filler most effective in supplying a network of binding material was found to be 40%.

Recently, successful use of alginates as binders for crustacean diets has been reported (Meyers et al., 1972), utilizing the

relatively unique ability of these marine hydrocolloids to react with polyvalent metal ions to form gels or solutions with very high viscosity. Application and control of the algin-calcium reaction, and its use throughout the food industry, has been described in detail by Andrew and MacLead (1970). The divalent metal ions (Ca^{++} is commonly used) form strong ionic bonds between adjacent algin macro-molecules (composed of mannuronic and gluronic acid units), resulting in a binding network. The solution thickens, gels, and then precipitates as the number of calcium-algin bridges increase. This reaction can be regulated with proper application of heat and use of phosphate sequestrants (i.e., Na Hexametaphosphate). Maximal efficiency is achieved when the alginate and sequestrant are dissolved prior to addition to the dry mix.

When used properly, sodium alginate yields a pellet with excellent stability and textural characteristics, remaining intact in water for 24 hours and longer. Initially, binding problems were experienced with rations containing fish meal and fish solubles due to the high calcium content and the nature of the Ca^{++}/alginate reaction of these two components. Binding quality was poor unless a phosphate sequestrant was added to the dry mix. The relationship of various formula components to diet stability is given in Table 5.

In formulas with little or no shrimp meal, a concentration of 0.75% alginate was sufficient to insure pellet stability for 24 to 48 hours. However, when shrimp meal was incorporated at more than 15%, 1.25 to 1.50% alginate was necessary to give comparable binding qualities. In early work using fish meal and/or solubles, concentrations of 2.5% alginate gave only 1 to 2 hours stability, but as noted, this has been overcome by addition of a sequestering agent. The amount of alginate used, and need for the sequestrant is related to the concentration of various components of the ration, especially the fish meal and solubles. In general, addition of 2.5% alginate (HV) and 1% sequestrant to the dry mix will produce a very acceptable feed. Alginates of lower viscosities, i.e., less than 400 cps, do not give comparable results. Exclusion of fish meal and solubles from the formula permits lower concentrations of binder and eliminates the need for the sequestrant. Grinding of the formula components, especially the shrimp meal and rice bran to a smaller particle size (0.1 mm mesh screen), greatly enhances stability characteristics of the pellet. Forester (1972) noted the significance of food particle size in the filtering apparatus of the prawn and ultimate effect on digestion.

An acceptable shrimp ration with HV sodium alginate as a binder is given in Table 6. This ration has been used intensively in laboratory tests of nutritive values of formulated diets. In six different experiments, brown shrimp (*Penaeus aztecus*) of mean initial weight 0.25 g to 3.03 g gained a mean of 1.36 to 1.43 g in 28 days.

Some observations concerning the economic feasibility of alginate-bound rations for commercial operations are in order. Alginates will increase feed costs by as much as $20 to $30 per ton depending on the amount of fish meal and solubles used and the stability desired. Reduction in costs may be achieved by using combinations of binders. Additionally important considerations are the extra processing time involved and the expense of removing additional moisture from the feed before storage. Possibly this feed could be made at the site of the culture operation and dispensed wet. Nevertheless, a portion of the added cost of using an alginate binder will be met by an overall decrease in loss of feed through disintegration, and more efficient conversion rates.

Alginate-bound rations certainly provide an excellent tool for laboratory investigations into various aspects of crustacean nutrition and culture in general. Most researchers cannot afford the equipment necessary to produce feeds by conventional methods. There are other means of producing rations in the laboratory, but few approaches can compete with the simplicity and versatility of the alginate "system".

We have examined other hydrocolloids to ascertain their binding qualities. Guar gum (0.75%) and algin (0.75%) exhibit a synergistic effect, and when used in combination, gave stability for as long as 24 hours, while guar gum alone at 1.0% imparted 7 hours durability to the pellet. In this regard, various other hydrocolloids should be examined to ascertain synergistic reactions, and their application in crustacean diets. Combinations of gums, i.e., guar gum and alginate, locust bean gum and alginate, carrageenan and locust bean gum, and guar gum and stamere Type HT gum, may be likely candidates for syngeristic studies. Proper use of sequestrants may permit incorporation of alginates at concentrations less than 1% in conjunction with various other gums. Certain commercially available fish foods incorporate a combination of guar and xanthin to impart stability, thereby reducing water fouling significantly.

Gelatin is a good binder at 1 to 2% levels, especially for diets lacking fish meal and solubles. However, gelatin is relatively expensive and if used, probably will find application at lower concentrations in conjunction with other effective hydrocolloids. A gelatin-base patented fish bait (Humphreys, 1969) has been proposed using hexamethylene tetramine (HMTA) as a hardener. The latter compound may have use with other binders, particularly a technical protein colloid ("TPC", Swift and Company, Chicago). This substrate appears promising, although a major drawback is the comparatively high (ca. 10%) concentration that may be needed. For some reason, diets containing fish meal and fish solubles do not exhibit good durability with TPC. On the other hand, tests with standard commercial trout feeds with TPC as a binder, show good durability. However, after a few days feeding, the TPC-bound rations were rejected by the shrimp. This is noteworthy, for obviously a prime requirement of a good diet is its continual acceptance by the animals throughout their growth

period. Recently, Sick et al. (1972) found collagen to be a suitable binding agent in pelleted shrimp food. Pellets with 5% collagen offered optimal consistency (i.e., ability to resist dissolution over a given period of time) over a 24 hour immersion in salt water.

In summary, alginates and other hydrocolloids, and particularly starches, have application in development of water-stable diets for crustacean culture. The selection of the individual binder will depend on the many considerations raised in this paper, including the nature of the culture system involved. Undoubtedly, no single binder will suffice for all species of crustacea, for rate of digestion of bound diets varies. Forester (1972) stressed that further study is needed before the potential value of different binding agents can be fully assessed. Use of substances and principles common to the food industry suggests that further extrapolation of basic principles in food formulation and fabrication to mariculture offer considerable promise to the investigator of crustacean nutrition and culture.

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Table 1. - Considerations in selection of suitable binders for crustacean diets

Application	
(Diet development and nutritional evaluation)	(Commercial production)
Cost and availability	
Adaptability to large-scale processing techniques	
Period of water stability desired	
Digestibility by animal	
Interaction with other constituents of diet	
Susceptability to attack by microorganisms of intestinal and growing area	

Table 2. - Common natural gums

Sea-plant extracts	Land-plant extracts, exudates, flours	Animal extracts
Agar	Pectins	Gelatin
Alginates	Cereal gums	Chitin
Carrageenan	Starches	
Furcellaran	Gum arabic	
	Gum karaya	
	Gum tragacanth	
	Gum ghatti	
	Guar gum	
	Locust Bean gum	

Table 3. - Application of gums in food products

Property	Application
Adhesive	Bakery glaze
Binding agent	Sausages
Emulsifier	Salad dressings
Encapsulating agent	Powdered fixed flavors
Film former	Sausage casings, protective coating
Gelling agent	Puddings, desserts, aspics, mousses
Protective colloid	Flavor emulsions
Stabilizer	Beer, mayonnaise
Suspending agent	Chocolate milk

Table 4. - Techniques used in processing of fish feeds

Types of feeds	Processing variables
Hard pellets	
Expanded pellets	Steam conditioning* (Pressure/Temperature)
Crumbles	
Blocks	Compression
Agglomerates	Particle sizing and texturing
Blower feeds	Moisture level
Autolyzed and hydrolyzed feeds	Binders (Benthonite, lignin Sulfonates, clays)
Oregon moist pellet	
Abernathy pellet	
Freeze-dried feed	

*Degree of starch gelatinization

Table 5. - Relation of algin, fish meal/solubles, and sequestering agent to pellet stability

Ration designation	% Fish meal	% Fish solubles	% Shrimp meal	% Algin	% Sequestrant*	Water Stability in hours
FST 2-470	—	—	—	0.74	—	48
3-470	—	—	—	0.74	—	48
4-470	—	—	36.0	1.50	—	48
4-670	13.0	2.0	35.5	0.75	—	0
5-670	5.0	1.0	30.5	0.75	—	0
6-670	5.0	1.0	20.5	1.50	—	1
1-970	8.0	2.0	30.5	1.00	0.30	12
1_a-970	8.0	2.0	30.5	1.00	0.45	24
2-970	8.0	2.0	30.5	1.00	1.00	36

*Calgon (Na Hexametaphosphate)

Table 6. - Composition of diet FDSC 5-5/70B

Ingredient	Percent
Sun-dried shrimp meal[1]	31.5
Menhaden Fish Meal	8.0
Soybean Meal	3.0
Rice Bran	51.0
Menhaden fish solubles	2.0
Lecithin[2]	1.0
Alginate[3]	2.5
Sodium Hexametaphosphate	1.0

[1]from Blum & Bergeron, Houma, Louisiana

[2]Alolec (Soybean Lecithin), American Lecithin Co., Long Island, N.Y.

[3]Kelgin, a high velocity (HV) algin product, Kelco Co., San Diego, California